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Spatial economic-hydroecological modelling and evaluation of land use impacts in the Vecht wetlands area

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Abstract

Wetlands provide many important goods and services to human societies, and generate nonuse values as well. Wetlands are also very sensitive ecosystems that are subject to much stress from human activities. Reducing the stress on wetlands requires a spatial matching between physical planning, hydrological and ecological processes, and economic activities. Spatially integrated modelling and evaluation can support this. The present study has integrated information and concepts from social and natural sciences to address the analysis and evaluation of land-use scenarios for a wetlands area in the Netherlands. The Vecht area is the floodplain of river Vecht, located in the centre of the Netherlands. This has resulted in a heuristic linking of spatial hydrological, ecological and economic models, formulated at the level of grids and polders. The main activities incorporated in the system of models are housing, infrastructure, agriculture, recreation and nature conservation. The formulation of alternative development scenarios is dominated by land use and land cover options that are consistent with the stimulation of agriculture, nature or recreation. Two aggregate performance indicators have been constructed from model output, namely net present value of changesand environmental quality. The spatial characteristics of these indicators are retained in a spatial evaluation that ranks scenarios.

1. Introduction

Wetland ecosystems, or ‘wetlands’, currently receive much attention in environmental science and policy. The widely supported Ramsar definition is a good starting point for the delineation of wetland ecosystems (Turner *et al.* 1998): “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed six metres” (Anon. 1994).

The sciences most concerned with the study of wetlands include earth sciences (in particular hydrology), biology (in particular ecology) and economics. The interest in wetlands has two origins. First, wetlands provide many important goods and services to human societies, ranging from flood control and nutrient removal to fish products and recreational opportunities. Second, wetlands are sensitive ecosystems that are subject to much stress from human activities. The latter include changes in land use, resource extraction, water regulation, drainage, and pollution. Reducing the stress on wetlands requires a spatial matching between physical planning (land use and water management), hydrological and ecological processes, and economic processes. Integrated modelling and evaluation tools can support such a spatial matching. In particular it has motivated an explicitly spatial approach in modelling and evaluation, involving three spatial levels, namely grid cells, polders and the region as a whole.

The present study aims to integrate information, concepts and models from social and natural sciences to analyse and evaluate land-use scenarios for an area in the Netherlands, the Vecht area (‘De Vechtstreek’). The groundwater table reaches the surface almost everywhere throughout this region. Typical wetland vegetation is found in both areas under agricultural use and natural areas.

The approach followed is based on explicit spatial scenario formulation, modelling and evaluation. A valuation study was considered too difficult, given the size and heterogeneity of the area. Valuation studies seem more suitable for smaller and more homogeneous areas (Gren *et al.* 1994; Turner *et al.* 1998; van den Bergh 1996).

This paper is structured as follows. Section 2 provides a short background to the study area, including a description of its present situation, of its historical development, of the problems it faces, of prevailing policy and management practice, and of development scenarios that will be studied with the integrated model and evaluation procedure. The present study has aimed to develop a method for examining solutions to these problems that is based on spatially disaggregated scenario analysis. This involves the following steps:

- description of the study area’s history, problems and policies (Sections 2.1-2.4);
- formulation of development scenarios on the level of grids and polders (Section 2.5);
- construction of a spatial model of the Vecht river basin, representing economic activities, hydrological processes and ecological responses (Section 3);
- development of performance indicators for the two evaluation objectives, viz. economic efficiency and environmental quality (Section 4.2); and,
- evaluation of the scenarios with respect to these criteria (Section 4.3).

A more detailed report of the study is van den Bergh *et al.* (1999).

2. The study area

2.1 Description of the area

The Vecht area is located between the river Vecht to the west, the sandy ice-pushed hill ridge 'Het Gooi' circa 8 km to the east, the Randmeer (part of a large lake which formerly was connected to the sea) to the north, and the city of Utrecht to the south where the hill ridge and the river almost meet (see Figure 2.1). The area is a wetland region with many shallow lakes and fens interspersed with agricultural fields Even where a solid soil is present, the groundwater table is close to the surface.

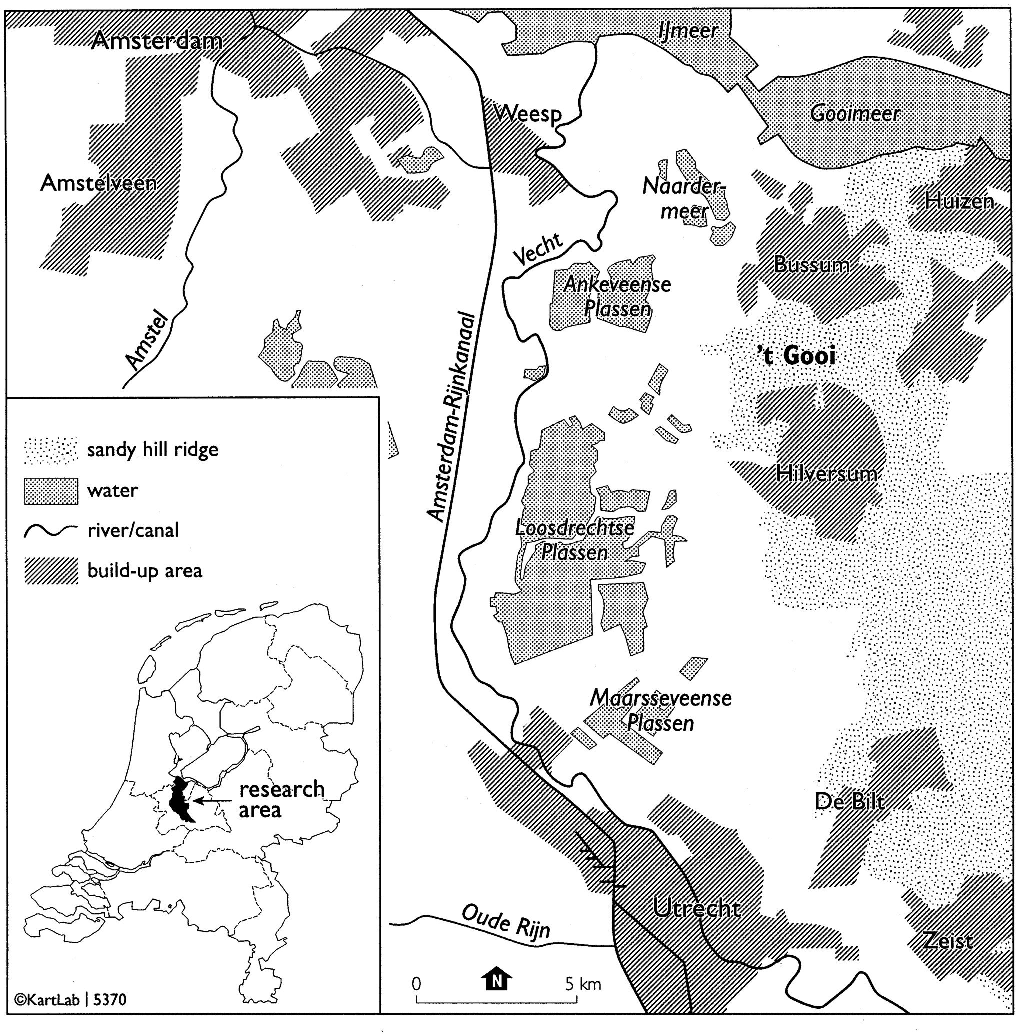

Figure 2.1 The research area and its surroundings.

The area is overlaps two provinces (North Holland and Utrecht), and includes 10 municipalities. Large urban centres lie mostly at the border or just outside the area. Agriculture and nature are the main land uses in the area; industry is virtually absent. Agricultural activities consist mainly of dairy farming. About half of the area is covered by pastures. Most of these are wet and located on peat soils. Surface water management in the polders is necessary to maintain these pasturelands and a groundwater level about 40 cm below surface.. A system of ditches and pumps maintains water tables at a precision level of centimetres. The pasturelands are important for nature as well as agriculture: e.g. they provide nesting areas for many wading birds, plant species characteristic of wetlands coexist with pasture species, and the ditches and canals provide habitat for a variety of aquatic species.

Most nature areas are owned by nature conservation organisations, both governmental and non-governmental. The variety in natural and artificial lakes, reedlands, marshes, grasslands and alder forests creates a mixture of different succession phases characteristic for these types of wetlands as well as a mixture of landscapes. The value of nature in this area is high, both from a national and international respective. The whole area is part of the Dutch Ecological Network; one of its lakes, Naardermeer, is listed as a Ramsar wetland. This value is also reflected by intensive outdoor recreation, including sailing, camping, and walking and cycling. In particular, many people from the nearby cities of Utrecht, Amsterdam and Hilversum are regular visitors of the area.

2.2 Historical development of the area

About a thousand years ago the Vecht are was largely bog (oligotrophic, *Sphagnum* spp)and uninhabited by humans. Its landscape was very different from the present one which is largely a product of human habitation. Habitation meant land reclamation, by making small ditches to drain the upper soil. In the 14th century these reclaimed areas were used for growing crops. In the 16th and 17th century, the demand for fuel by the growing populations of Amsterdam and Utrecht was met, in part, by mining peat from the bogs. This resulted in an enormous change in the landscape. Peat was dredged, leaving behind small turf ponds interspersed with strips of uncut areas where the (wet) peat was deposited to dry. Profit motives kept these strips as small as possible. Sometimes the strips were so small that wave activity in the turf ponds eroded them, and as a result many large lakes developed during the 18th and 19th centuries. One of these lakes was then reclaimed in the 19th century for agricultural development (polder Bethune). A natural lake, Horstermeer, in the centre of the Vecht area was also reclaimed during this period, used for agricultural development.

In the 17th and 18th century the landscape at the borders of the Vecht area was also re-shaped. Wealthy merchants from Amsterdam established estates with extensive gardens close to the river Vecht. The western border near the hill ridge - ‘Het Gooi’ - underwent a similar change. Here the sandy soil was excavated in the 17th century and used in the construction of the now famous canals in Amsterdam. The profits from this venture were used to establish estates in the areas from which the sand originated. These estates are now famous for their contribution to landscape and architectural beauty.

Until the middle of this century the functions agriculture, nature and housing in the Vecht area were in balance. The intensity of agriculture and other human activities was relatively low and there was a high biological diversity, particularly of bird and plant species. The first decade after the Second World War saw the beginning of drastic changes.

2.3 Threats to the wetlands

The problems relating to the Vecht wetlands relate to its hydrology, its chemistry and its physical planning. The balance between surface water and groundwater has changed. Groundwater and rainwater are the original sources of water for the wetlands. The input of groundwater has decreased substantially. During the 1970s, 20 million m^3 of drinking water were abstracted annually from the hill ridge, resulting in lower water tables and a reduction of seepage into the wetlands. To compensate for high levels of evapotranspiration in the summer and to minimise mineralisation of peat soils due to low water tables, surface water from the river Vecht was permitted to enter the area. Further, the two deep polders (Bethune and Horstermeer) have effectively reversed the direction of water flows. This was originally east to west, from the hill-ridge to the river. Being deep polders with water levels artificially kept low, they drain water from surrounding areas. Water flows are now more wets to east, from the river to the wetlands.

A second problem, partly related to the changes discussed above, is that of water chemistry. The wetlands are suffering from nutrient enrichment as a result of a number of factors: the penetration of nutrient-rich water from the river Vecht into the wetlands, intensified agriculture, local sewerage treatment plants, mineralisation of peat soils, and outflow from illegal waste-dumps. Increased phosphorus and nitrogen concentrations in surface water have caused numerous algal blooms and a deterioration of the quality of nature in the area. In particular, certain types of aquatic vegetation have disappeared, including a number of important 'red list' (threatened and protected) species. This problem is exacerbated by the absence of buffered groundwater in the root zone of the vegetation and increased acid deposition from the air.

A third problem is the pressure from the spatial pattern of human activities. Recreation and nature are the main 'activities' in the central parts of the Vecht region. Recreation has been intensifying. New marinas and campgrounds have been created , despite the potential conflict with nature and physical planning by local municipalities. Attempts by the agricultural sectors to intensify their activities have met with mixed success due to technical restrictions on water tables and physical planning regulations to protect nature. Agriculture is the dominant economic activity in terms of profits in the north-west and the south.

The post WWII landscape, comprising extensive agriculture and relatively undisturbed wetlands, has been replaced by a landscape interrupted by human activities, notably housing and infrastructure. The area available for nature has decreased in size and has been fragmented. Many nature areas are still present, but are no longer interconnected. As a result, many areas have become too small to continue to support viable plant and animal populations.

2.4 Policy and management

Policy within the study area focuses on specific activities, such as recreation or water use, or towards the combination of different activities in specific areas via land use regulation or physical planning. Policy derives from three levels: national, regional and local. Municipalities and provinces, together with various special interest groups, undertake the actual management.

The national government preserves the international value of nature in the Vecht area via the Ramsar status of the wetland reserve 'Naardermeer'. This reserve is also incorporated in the assigned areas in the Habitat Directive (EU). The entire Vecht area is in the list of 'Areas I mportant for Birds' (Birds Directive, EU), which will be integrated with the Habitat Directive in the European ecological network NATURA 2000.

At the national level the Vecht area has been assigned the 'green course' label (VROM 1990), implying that the area is to remain rural or natural. In the Dutch Nature Policy Plan (LNV 1990) the entire Vecht area is defined as part of the ecological network of the Netherlands. This requires conservation of nature reserves and that farmers should actively stimulate the development of nature in agricultural areas between nature reserves.

Physical planning enacted by the two provincial governments is consistent with the national policy, but is far more detailed. It defines the nature and agricultural areas, denotes areas for construction of buildings, and economic development. Trade and industry in the area are very much restricted by physical planning. Inside the wetland area only a few small factories are present. Most other industries are located along the river Vecht and along a canal at the eastern border of the area. The two provinces have different opinions about agricultural development in the Vecht area. The province of Utrecht strives as much as possible for physical or spatial separation of economic activities from nature areas while the province of Noord-Holland aims to establish an area where nature and agriculture are interwoven. The rationale behind the latter is that both nature and agriculture are part of the cultural landscape.

At the local level 10 municipalities have a policy conforming to provincial policy. Nevertheless, local decisions, especially with regard to housing, often conflict with higher level decisions. Other important local institutions are Water Boards, which have created a separate set of regulations and taxes to support the management of surface water tables and surface water chemistry. In addition, several local, regional and national nature preservation and nature management organisations, notably 'Natuurmonumenten' (an NGO)and 'Staatsbosbeheer' (the forestry service within the Ministry of Agriculture, Nature and Fisheries) have developed very detailed plans for nature creation, management, protection and restoration. Specific local and regional nature management activities focus on abstraction and storage basins for drinking water, restoration projects, and nature development projects.

2.5 Development scenarios for the Vecht area

This section presents development scenarios for the Vecht area that will be tested by the models and subsequently evaluated , as reported in later sections. These scenarios reflect choices made in physical planning, nature policy, agricultural policy, and regulation of recreation, i.e. the main political and economic interests in the area. The scenarios are in line with present policy. In particular the nature and recreation scenarios attempt to improve environmental quality in a corridor that runs north-south through the study area. The scenarios are spatially disaggregated and are formulated at the level of grids and polders. The hydrological parameters are defined at a grid level (500 m x 500 m) and the economic parameters at a polder level (on average 200 ha). This is related to the fact that the hydrological model assumes homogeneity at the level of grids, and the economic model at the level of polders. Any information at a grid level can be easily aggregated to the polder level. Given that the integrated modelling approach is static, he scenarios are also static. They will be used in a comparative static analysis, where changes from a reference (or base) scenario are compared among alternative scenarios. Each scenario specifies land use and water levels at the polder level for the 73 polders which comprise the study area (see Figure 2.2).

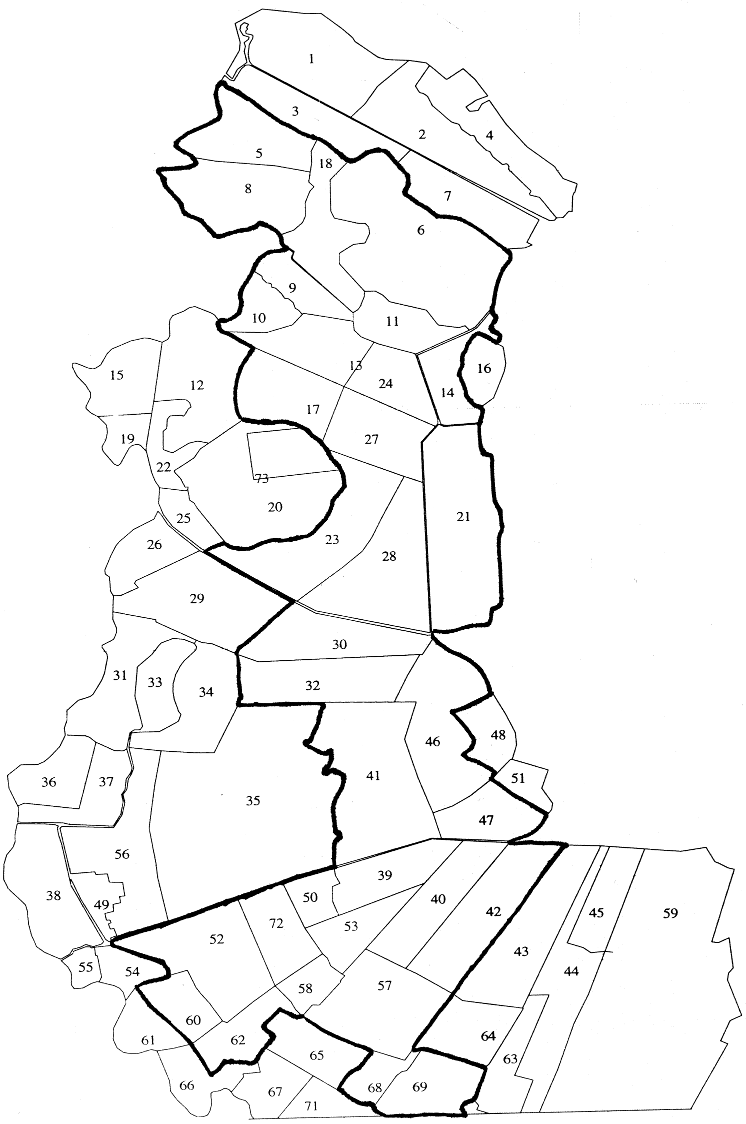

Figure 2.2 The study area, its polders, and the corridor targeted by the scenarios for improved environmental quality.

The four scenarios for development of the Vecht area are the following (see Table 2.1):

I. Reference (base or business-as-usual)
II. Stimulation of agriculture
III. Stimulation of nature
IV. Stimulation of recreation

These scenarios take the present conditions into account.. Scenarios II to IV focus on core human activities in the region, and allow comparison of quite distinct, although still realistic, future organisations of the Vecht area. Table 2.1 summarises the scenario settings.

Table 2.1 Development scenarios for the Vecht area.

Scenarios	Hydrological settings per polder	Economic settings per polder
I. Reference	present situation in all polders	Present situation in all polders
II. Stimulation of agriculture	0 = no change in water table	0 = no change in land use
(3 types of polder settings)	1 = no change in water table	1 = 50% conversion of present to intensive agriculture
	2 = –0.2 m	2 = 100% conversion of present to intensive agriculture
III. Stimulation of nature	0 = no change in water table	0 = no change in land use
(3 types of polder settings)	1 = +0.1 m	1 = 50% of present agriculture converted to nature
	2 = +0.2 m	2 = 100% of present agriculture converted to nature
IV. Stimulation of	0 = no change in water table	0 = no change in land use
Recreation	1 = +0.1 m	1 = 50% of present agriculture converted to nature, and investments for outdoor recreation
(5 types of polder settings)	2 = +0.2 m	2 = 100% of present agriculture converted to nature, and investments for outdoor recreation
	3 = polder flooded	3 = polder flooded and opened for recreation
	4 = no change in water table	4 = water based recreation stimulated or intensified on existing open water

3. The integrated system of spatial models

3.1 Method of integrated research

The method of integrated study addressed integration at four levels, as shown in Figure 3.1.

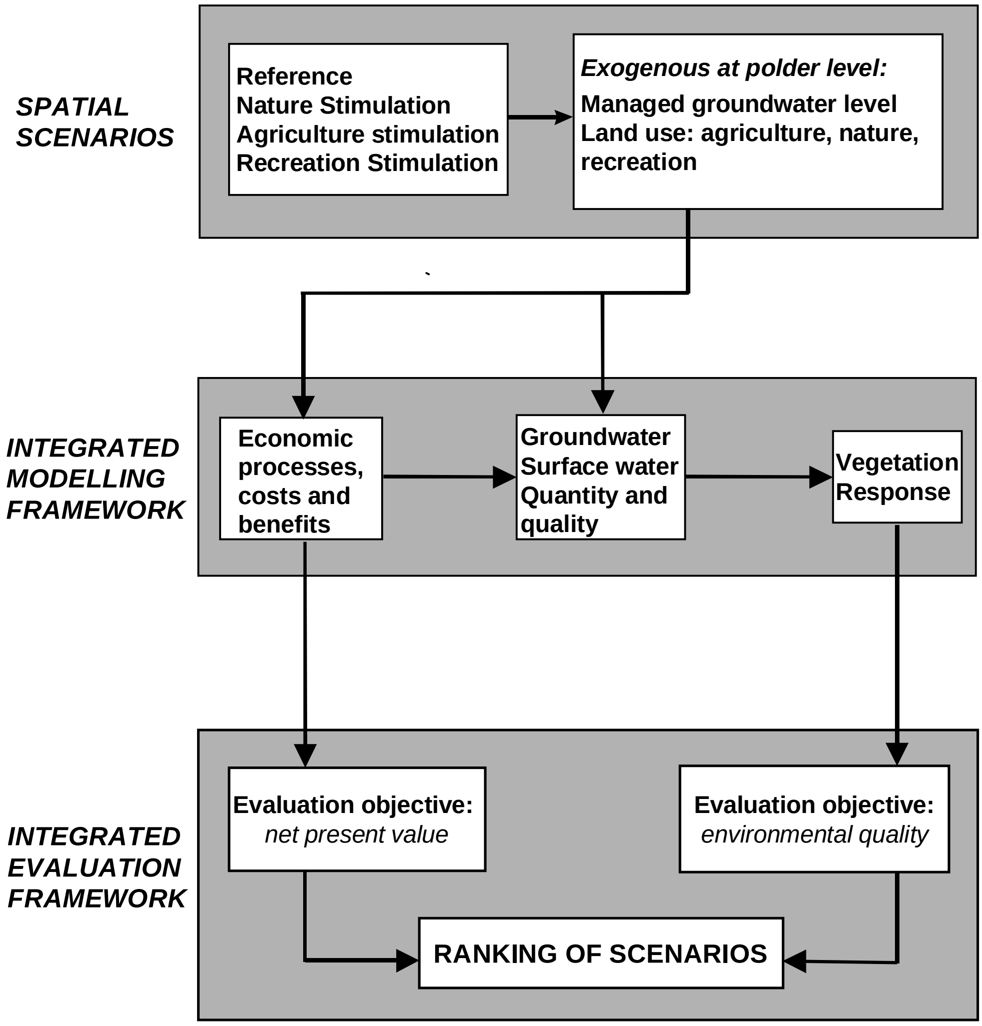

Figure 3.1 The integrated approach followed in the 'Vecht area' case study.

The first level involves the formulation of development scenarios for the Vecht area that include consistent settings for the hydrological and economic parameters. This has been discussed in Section 2.5. The second level entails heuristic integration of hydrological quality and quantity modelling, vegetation response modelling, and economic modelling and accounting. The hydrological-ecological part of the modelling and analysis was performed on a grid basis, and subsequently aggregated to the level of polders, to make it consistent with the economic analysis. Integration at this level includes explicit links between the natural science and economic models. This has focused on the inclusion of nutrient surpluses from agriculture in the water quality modelling, and on the influence of water quantity and quality on plant species occurrence.

A third integration level aggregates output from the models into performance indicators reflecting objectives in the evaluation. While the full study generated three performance indicators (see van den Bergh *et* al. 1999), this paper presents only two: net present value and environmental quality. The final and essential step in the integration is the evaluation procedure in which these performance indicators were used to rank scenarios. Two objectives drive this evaluation: economic efficiency and environmental quality. The latter attempts to capture ecological criteria describing how well wetland ecosystems are functioning.

3.2 Ecohydrological model

Nature in undisturbed wetlands is in balance with its abiotic conditions. Since fauna are dependent on the vegetation structure, the aquatic and terrestrial vegetation represented by characteristic species is the key ecological element to be predicted. The basic site factors influencing the presence of a certain type of vegetation are local water levels (hydrology) and local concentrations of nutrients and major ions. These chemical conditions are strongly influenced by the transport of chemicals by sub-regional water flows, and to some extent by atmospheric deposition. The water flows result from an interaction between groundwater and surface water.

Against this background the natural science modelling has linked three models:

1. a model of water quantity, which describes amounts of groundwater and surface water expected at specified locations in the present hydrological conditions;
2. a model of water quality, which describes the chemistry of groundwater and surface water at specified locations; and
3. an ecological model, which describes the expected presence of 260 wetland plant species at specified locations given local environmental conditions.

The quantitative water model creates input for the qualitative water model, while both these models predict the abiotic site conditions that serve as input for the vegetation response model (see Table 3.1). A set of boundary conditions is needed to define the domains of the models. Some of these boundary conditions can be manipulated in scenarios, others are static in the time domain adopted here, such as soil texture. Each of the models requires spatially differentiated input. For the storage and representation of spatial data a raster or grid representation has been chosen with a raster cell size of 500 x 500 meters in ArcInfo and PCRaster GIS. A raster representation is suitable to depict spatially varying continuous variables such as surface level and groundwater tables. Overlay computations can be done quickly with these raster maps. The most important spatial unit in this study area is the polder, which in all cases is larger than such a raster cell.

Table 3.1. Input and output of the three natural science models

Model	Input	Output
(1) quantitative hydrology	- surface water tables	- level of groundwater per cell
	- groundwater tables	- water balance per polder
	- boundary conditions in soil	
(2) qualitative hydrology	- chemistry of local surface water, groundwater and rain;	- the chemistry of surface water and ground water
	- the water balance from (1)	
(3) ecology / vegetation	- water tables from (1)	- the probability of encountering 265 plant species per cell
	- chemistry from (2)	
	- local conditions per polder	
	- some management options	

The flow of groundwater is modelled with the model code MODFLOW (McDonald and Harbaugh 1984). This code solves three-dimensional flow problems using a finite diffe r-ence matrix-solving module, and has been widely applied. The model area is divided into several layers of blocks with the same lateral conductivity; each block is assumed to be homogenous in conductivity. In each block a centred point is defined for which the flow is calculated. For a three-dimensional set of model nodes, the model code generates a solution for the differences between each node. Apart from the flow term between nodes other sources or sinks of water can be modelled (Hill 1990; McDonald *et al.* 1991; Prudic 1989). The hydrological model covers an area of approximately 24 by 28 km. Water budget terms are calculated for each cell in the whole area.

In order to model the chemistry in surface and groundwater each cell in the quantitative model of the top layer is considered as a bucket. The chemical conditions of groundwa-ter, surface water and precipitation entering each cell contribute proportionally to its net chemical concentration. For each model cell net in- or out-fluxes of groundwater, surface water and precipitation are known; only the net input fluxes are considered. Precipitation is always an input flux (a surplus of 200 mm per year). Changes in boundary conditions of the quantitative model cause fluxes to model cell and result in revised water chemistry conditions.

In the context of the nature and agriculture scenarios, extra conditions are incorporated in the qualitative model. This includes technical removal of phosphate from surface wa-ter through a phosphate removal plant. Under the nature and recreation scenarios, several polders with high nature values are provided with such plants. The economic model describes (changes in) the intensity of agricultural practices and subsequently predicts changes in the amount of nutrient run-off at surface. This, together with the effects of mineralisation , is converted to the surface water chemistry.

The ecological model ICHORS (Barendregt *et al.* 1993) predicts the occurrence of wetland plant species. The model is based on general linear modelling regression techniques (Nelder and Wetherburn 1974). It describes the statistical relationships between the conditions in the environment (a total of 25 variables) and the presence of 260 plant species. This model was selected because it is non-spatial, can be used on a grid scale with changes in environmental conditions, and has been applied in earlier studies addressing changes in hydrology (see Barendregt *et al.* 1992; Barendregt and Nieuwenhuis 1993). The statistical relations in ICHORS originate from data sets with hundreds of samples collected from all types of wetlands throughout the region. The environmental conditions comprise soil type, land use management, groundwater level, and concentrations of major ions and nutrients in groundwater or in surface water. The model estimates the probability that each wetland plant species will be found at a given site. Since environmental conditions can result from specific management options or external events and trends, the model is suitable to estimate the effect of scenarios.

3.3 Economic model

The economic model was developed on the basis of two aims:

1. present economic indicators for each scenario and polder, to enter the multi-criteria evaluation procedure, and perform financial cost-benefit analysis; the economic indicators calculated are the changes in net present value and employment, and;
2. calculate the changes in the run-off of nutrient flows under each scenario, to enter into the ecohydrological model; this covers environmental indicators for the run-off and surplus of nitrogen and phosphate.

The economic model focuses attention on financial cost benefit analysis and indicators, i.e. it only considers financial transactions and excludes (social) costs and benefits for which no market price is paid, such as those related to changes in nature. The reason is that this study also present separate ecological indicators that measure improvements in environmental quality. In the evaluation step economic and ecological indicators are combined. This means that if the environmental improvements would be incorporated in the economic indicators the evaluation would represent a sort of double-counting.

In order to perform the above task a spatial economic model is formulated that describes agriculture, nature conservation and outdoor recreation. The inputs to the spatial-economic model consists of the settings under specific scenarios as defined in Section 2.5; economic, agriculture, environmental data on a hectare level for the various scenarios and settings; and environmental quality indicators per polder calculated in Section 4.2. Table 3.2 lists the input and output of the spatial-economic model.

Table 3.2. Input and output of the spatial-economic model.

Input	Output
Scenarios and settings (per polder and # ha)	Economic indicators (per polder) (input in evaluation procedure)
Economic and nutrient data (per ha)	Nutrient indicators (per polder) (input in hydrological model)
Environmental quality indicators (per polder) (output from hydrological model)	

Under the agricultural scenario, agriculture is intensified in various polders (see polder settings in Table 2.1). The revenues are calculated per hectare in the present and intensified situation. The changes in revenues compared with the present situation are the benefits. In addition, employment and environmental indicators are calculated. Under the nature scenario, parts of agricultural land are converted into nature. The costs of this conversion include those of acquisition, restructuring and maintenance, as well as the costs of foregone benefits of agriculture (i.e. the opportunity costs). These opportunity costs are the current revenues of agriculture. The environmental indicators that change due to a reduction in agricultural land are measured in physical terms. The recreation scenario is similar to the nature scenario, but with some additional changes relative to the nature scenario: the land areas that are converted into nature are opened for recreation; some polders that are open water are opened for recreation; and some polders are flooded for the purpose of water-recreation.

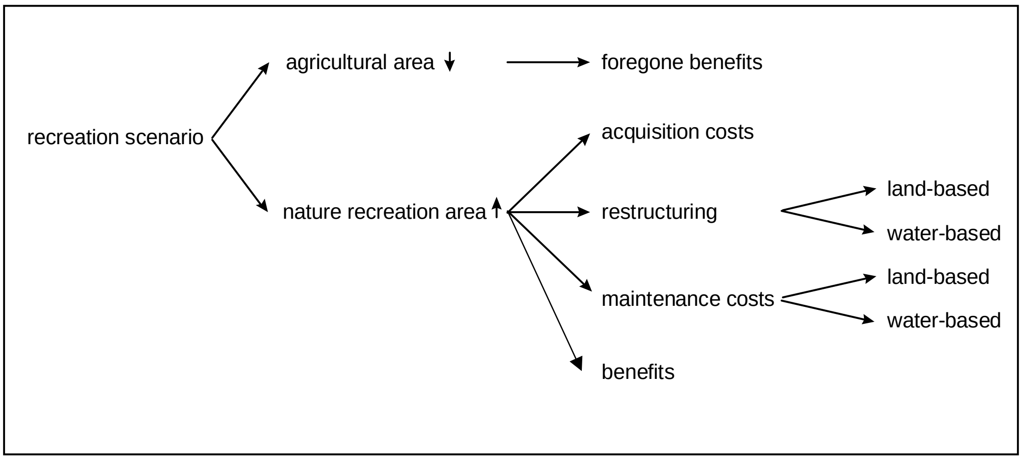

Figure 3.2. The various costs related to the nature-recreation scenario.

By converting land from agriculture to nature and to recreation various types of costs arise. The first type are opportunity costs (or foregone benefits) resulting from a reduction in agricultural area. The second type of cost is related to an increase of area for nature. The costs of stimulating nature are divided into four categories (see Figure 3.2): acquiring costs, restructuring costs, maintenance costs, and opportunity costs (foregone agricultural benefits). The costs of acquiring area arise at one point in time. The costs of restructuring are spread over ten years. Some costs can be distinguished into costs relating to land-based and water-based recreation.

4. From models to evaluation

4.1 Model results

The natural science modelling gave rise to the following insights. Environmental conditions for the stimulation of characteristic wetland species in the Vecht area should be as follows: high water tables; water with low concentrations of chloride, magnesium, sulphate, sodium, potassium and nutrients (phosphorus, nitrogen, ammonium); and buffered conditions with notably high pH-values due to high concentrations of calcium and hydrocarbonate. Two opposing influences exist on water quality and subsequently on the presence of the desired plant species. First, drainage attracts fresh groundwater from surrounding areas which positively affects the wetland species. Second, maintaining high water tables inevitably means the inflow of water from the river Vecht, which is rich in nutrients and has a relatively high salinity level; this has a negative effect on the wetland species. The net effect of these processes is also influenced by: acidification resulting from the infiltration of rainwater; drainage with subsequent mineralisation of peat and release of additional nutrients; and intensification of agriculture with extra input of manure and fertilisers. As a result of these - partly conflicting - processes, stimulating nature will only be possible in specific parts of the region.

The results obtained with the vegetation response model are as follows. Plant species characteristic for fresh and nutrient-poor locations are predicted at isolated locations where there is discharge of groundwater. Many species characteristic of polluted water are predicted at locations where river water dominates the water balance. It appeared that many species are only stimulated in a restricted number of grid cells, namely those that are much affected by the conditions in the scenarios. Although the local population of such species will respond, changes in the respective population may be less significant and run the risk of not appearing once aggregated, in the evaluation of the whole area.

In order to be used as a spatial model the input of the vegetation response model needs to consist of (an input map of) spatially differentiated data. Therefore, the ICHORS regression equations are imported into a GIS system (van Horssen *et al.* 1999). This leads to an output map with plant response values for each species per grid cell. Some of the input data for the regression models is static information, e.g., soil texture and land use. Other data concerns hydrological information on discharge or recharge of groundwater, groundwater table and depth of surface water, and the chemistry in surface water and groundwater. Evaluation of the model output arising under different sets of conditions allows assessing whether certain groups of species are stimulated under particular scenarios (Barendregt and Nieuwenhuis 1993). An example of the results the vegetation response model is given in Figure 4.1.

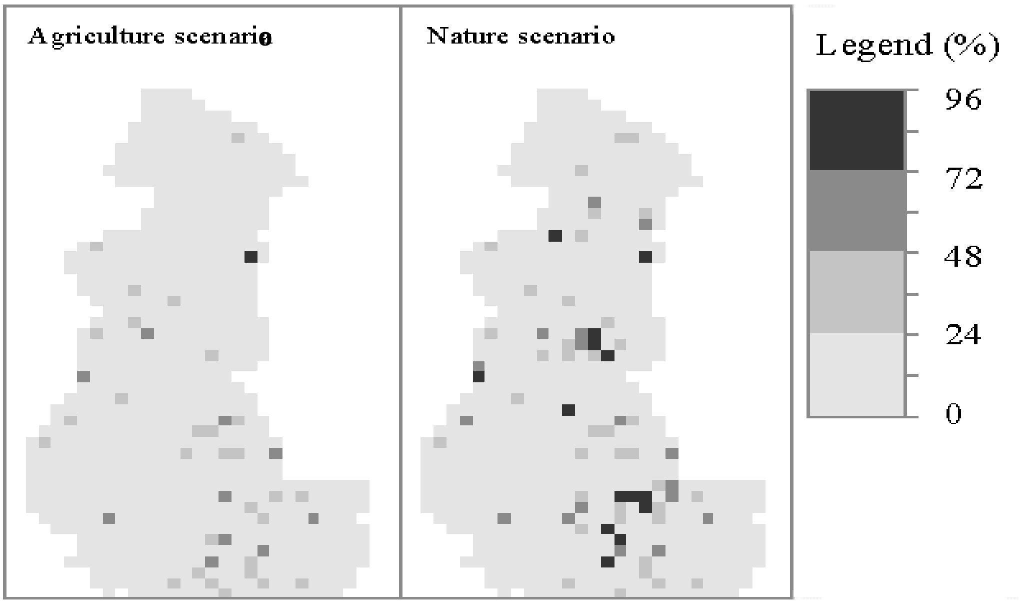

Figure 4.1. The predicted probability of presence of the aquatic plant species 'Utricularia vulgaris' per grid cell in the agricultural scenario (left) and in the nature scenario (right).

Table 4.1 and 4.2 give a concise overview of the results obtained with the economic model. Table 4.1 shows the net present value (NPV) of changes aggregated per subregion (North, Middle, South and Total). The NPV of the agricultural scenario is calculated from the increased benefits of intensifying agriculture in various polders. The intensification of agriculture has a positive effect on the NPV, because the benefits per hectare of agricultural land increase.

Under the nature and recreation scenarios, part of the agricultural land is allowed to return to nature. The difference is that, under the recreational scenario, nature areas are open to recreation. Further two polders in the recreation scenario are inundated for water-based recreation. Under the nature scenario the costs of converting agricultural land are the only financial indicators on which the calculation of the NPV is based. Therefore, the NPV is negative, i.e. there are costs, but no financial benefits. In the recreation scenario some acquired polders are converted into recreational areas: both land- recreation and water-based recreation. The NPV of the recreation scenario is based on the costs of converting the land (including maintenance and opportunity costs) and the benefits of spending on recreation. The resulting NPV under the recreation scenario is positive: the increase in recreational benefits (i.e. the spending on recreation) outweighs the costs of converting to this land use. In the nature and recreation scenario three phosphate removal plants are installed to extract phosphorus from the water in an attempt to improve the quality of the water, and so the quality of nature.

Table 4.1 The net present value per region under the three scenarios (changes in million Euro guilders, relative to the reference scenario).

Region	Agricultural scenario	Nature scenario	Recreation scenario
North	76.99	-109.02	698.73
Middle	35.00	-34.20	741.61
South	63.60	-83.16	542.29
Total	175.59	-226.38	1982.65

4.2 Objectives and performance indicators

Two objectives for scenario evaluation evaluation were identified: net present value and environmental quality. Net present value has been discussed in previous sections. This section describes the construction of an index of environmental quality based on the output of the vegetation response model and, to a lesser extent, of the hydrological model. Output from the former consists of the probability of occurrence of some 250 plant species per 500m x 500m grid cell.

At a theoretical level indicators of environmental quality attempt to capture three ecosystem characteristics (see Schaeffer *et al*., 1988; Karr, 1991; Costanza *et al.* 1992; van Ierland and de Man, 1993; Steedman, 1994; Holling *et al.* 1995; Ghilarov, 1996;Folke 1999): process, structure, and resilience. These aggregate characteristics were taken to be represented by:

- Process: presence of species typical of nutrient-rich conditions and presence of species with the potential to form peat;
- Structure: presence of species typical of fen and peatlands;
- Resilience: presence of species suggesting that the natural successional series in these wetlands has been diverted.

A selection of plant species per category was made on the basis of expert judgement. Four indicators (Eutrophication, Peat-formation, Diversity and Non-resilience) were then calculated per grid cell as the average probability for the selected speciesper scenario. In the case of the peat-forming indicator, an additional constraint was added – the value of this indicator was set to zero when water level (as estimated by the hydrological model) was lower than 15 cm below ground level. Such water levels would prevent peat formation even if the relevant species were present. Grid cell values for these indicators were then aggregated to derive polder values. Further, the Eutrophication and Non-resilience indicators were given a negative value as they make negative contributions to environmental quality.

The indicators were then combined to derive an index of environmental quality. In this combination, it was assumed that the three ecosystem characteristics contribute equally to environmental quality, and that the eutrophic and peat-forming indicators contribute equally to ecosystem process. This procedure is summarised in Figure 4.2 and the results are given in Appendix Table A1.

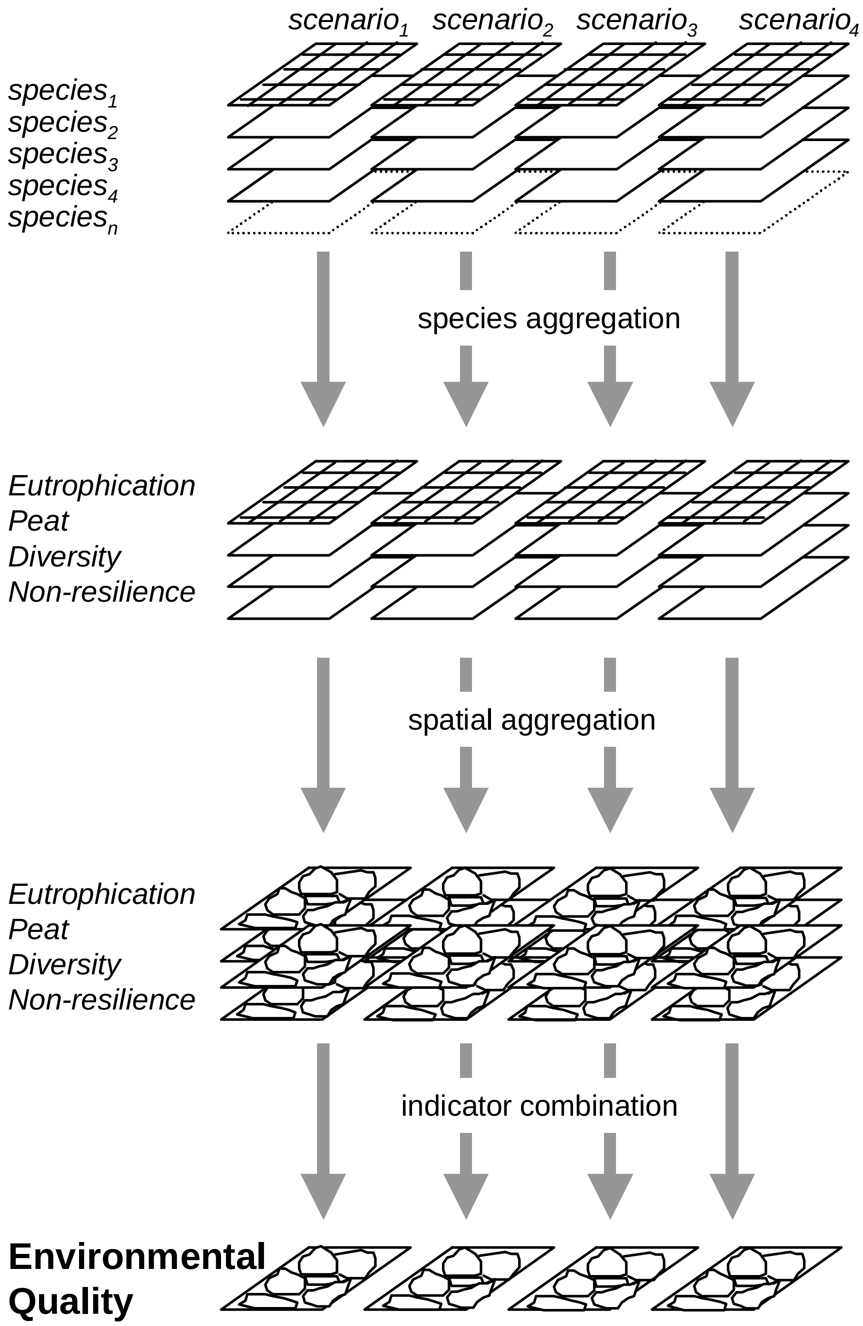

Figure 4.2. Aggregation of model output to an index for environmental quality.

The scenarios, particularly Nature and Recreation, focused on stimulating the return of typical wetland vegetation in a corridor which runs from north to south through the study area. The results show that this was achieved, although the degree of improvement to nature was somewhat limited. There are two likely explanations for this.

First, indicators for environmental quality require aggregation across species and across space. The results obtained from the vegetation response model, when closely examined, show that a scenario only changes the probability of occurrence of a small number of species per grid cell *vis a vis* the reference scenario. This is the product of the heterogeneity of the study area. Aggregation across species could be diluting real improvements to wetland quality. Second, raising water levels does not necessarily mean improving conditions for wetlands due to the hydrological balance between nutrient-rich Vecht river water and nutrient poor groundwater. The influence of groundwater can be increased only by further reducing groundwater abstraction in the hill ridge. This factor was not incorporated in the scenarios.

4.3 The evaluation

The evaluation aimed at ranking the scenarios and assessing any sensitivity in this ranking. A combination of multi-criteria and spatial evaluation (see van Herwijnen 1999; van Herwijnen and Rietveld 1999) within the software package DEFINITE (Janssen and van Herwijnen 1994) was used[1]. The objectives of the evaluation were: economic efficiency (approximated by NPV) and environmental quality (approximated by the index described above). These two performance indicators were calculated for each polder.

The subsequent evaluation of the scenarios on the basis of these indicators can proceed in two ways, as indicated in Figure 4.3. The two paths differ according to the order of the two sub-steps:

1. aggregation across space, deriving a single value for each performance indicator per scenario, then standardising and combining indicators to derive a single value per scenario; or,
2. standardising and combining performance indicators, deriving a single value for each location per alternative (a map per alternative), then aggregating across space to derive a single value per alternative.

Van Herwijnen (1999) has shown that these paths can yield different rankings of scenarios, and different insights into their success or otherwise. The first path above would lead to the results presented in Table 4.1. Scores for each indicator have been standardised between 0 and 1, then combined in the last row. The combination rule is the simplest, namely additive with equal weights. The combination of NPV and the index of environmental quality is termed ‘welfare’.

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[1] Earlier studies have focused on cost-benefit analysis of specific scenarios and measures for the Vechtstreek (Barendregt *et al.* 1992; Bos and van den Bergh 1997).

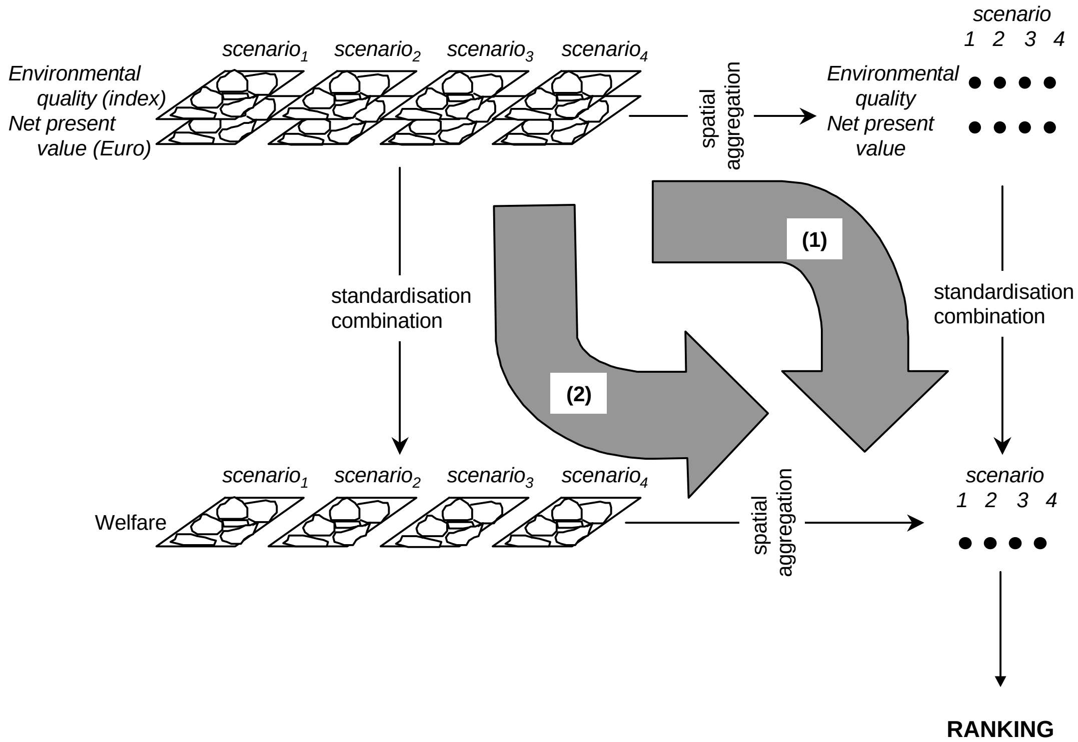

Figure 4.3. Alternative paths for evaluation of scenarios according to objectives with a spatial character.

Table 4.1. Derivation of a single score per scenario according to path 1 in Figure 4.3

Performance indicator	Unit	Reference	Agriculture	Nature	Recreation
Net present value	NPV (million ε)	0	175.6	-226.4	1,982.6
Standardised score	*Index [0,1]*	*0.10*	*0.18*	*0.00*	*1.00*
Environmental quality	Index [0,100]	0	0.24	7.24	6.22
Standardised score	*Index [0,1]*	*0*	*0.03*	*1.00*	*0.86*
Welfare	***Index [0,2]***	***0.10***	***0.22***	***1.00***	***1.86***

The ranking of the scenarios, from most to least preferred, is clearly:

Recreation > Nature > Agriculture > Reference.

Using the same procedures for combining the two performance indicators, Path (2) from Figure 4.3 leads to the set of maps presented in Figure 4.4. Note that the corridor up the middle of the region and targeted for nature restoration (see Section 2.5) is also shown in these maps. The darker the map, the more preferred the scenario.

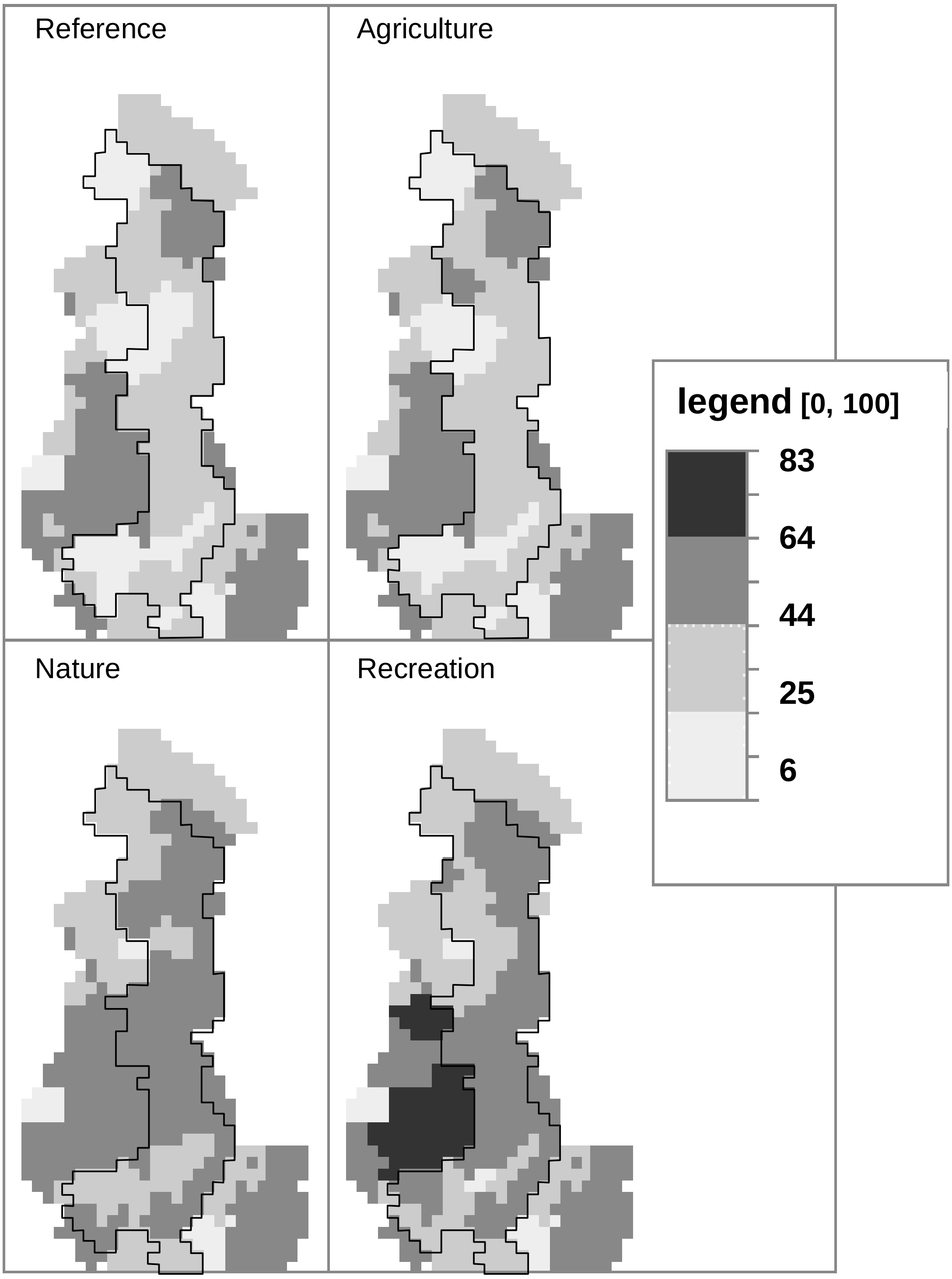

Figure 4.4. Welfare per polder

Although a visual ranking from these maps suggests the same result as for Path (1), there is uncertainty in ranking of the Nature and Recreation scenarios. (This is also true for the Agriculture and Reference scenarios, but since they score so poorly, their precise ranking is less relevant.) Not only is it difficult to separate these two scenarios, but polders that score highest in the Recreation scenario lie outside the targeted corridor. If only this corridor were considered, Figure 4.4 suggests that Nature might be the more preferred of the two scenarios.

Figure 4.5 tests how different the results from the two scenarios are by presenting difference maps for welfare. These maps consider only the Recreation and Nature scenarios, and show which of the two scores best for each polder. White areas denote polders where the two scenarios score equally (Figure 4.5a) or where the difference between the two is less than or equal two one unit of welfare (Figure 4.5b). Many of the polders where Nature is the better scenario are lost in Figure 4.5b showing that the difference between these scenarios is very small. No polders with Recreation as the better scenario are lost in Figure 4.5b. This suggests that, where Nature is the better scenario, Recreation is often a close second while the converse does not hold.

The conclusion from the above discussion is the following ranking of scenarios:

Recreation > Nature > Agriculture > Reference

However there is a degree of uncertainty associated in the preference for Recreation over Nature. Maintaining spatial detail in the evaluation has exposed this uncertainty.

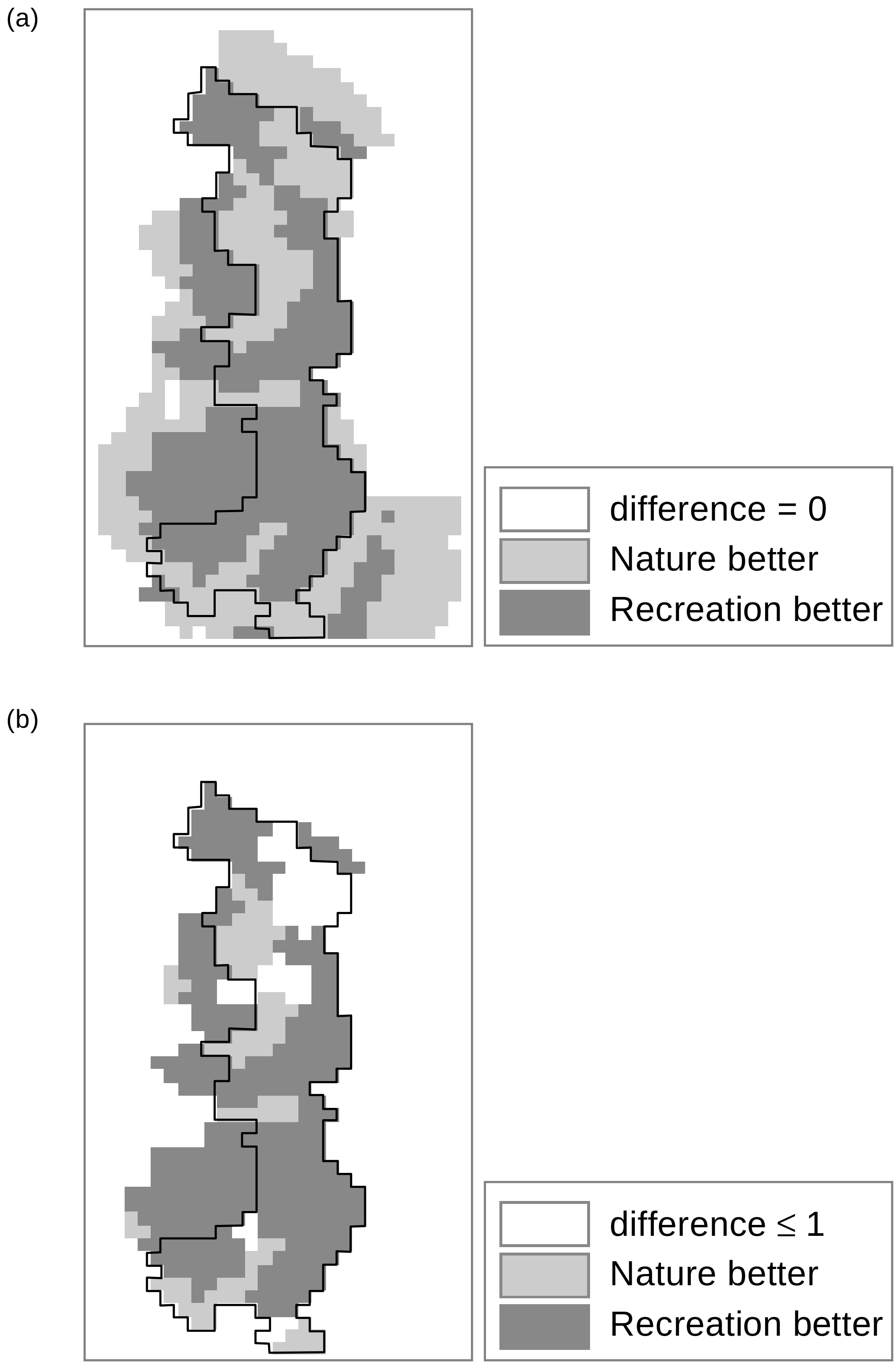

Figure 4.5. Difference map for welfare (Nature against Recreation).

5. Conclusions and further research

The Vecht area is a wetland area with many functions, uses and values. This study has focused on the spatial dimension of interactions among hydrological, ecological and economic processes and clearly shows that spatial differences matter..

Spatial differentiation started with a formulation of scenarios, at the polder level, in which either agriculture, nature, or recreation was stimulated. A system of interactive models generated output from which various indicators were calculated for each scenario. The natural science component of this study consisted of water quality and quantity models that generated spatial abiotic conditions for a vegetation response model. The economic component was represented by a spatial-economic model describing agriculture, nature conservation and recreation, generating output which input to the hydrological model. Output from the models was used to generate aggregate performance indicators used to evaluate the scenarios.

This evaluation showed that the Recreation scenario was most preferred scenario with Nature the second most preferred. However care should be taken with this result as no feedback from increased recreational use to environmental quality has been considered. Examples of such adverse impacts include trampling, litter, and noise. Species that are not represented in the ecological model, such as birds and mammals, are likely to be sensitive to these adverse effects and to large numbers of visitors. A degree of uncertainty in this ranking appeared when the spatial character of the performance indicators was maintained for as long as possible during the evaluation. The study areais too large to be treated as a hydrologically, ecologically or economically homogeneous area. More research is possible on details of the various elements of the method of integrated research adopted in this study. The different types of intensive and extensive agriculture may require more attention. Further work is also possible on specifying set-up costs of scenarios, which have been only roughly covered here. Finally, it would be interesting to look at other scenarios, such as futurist ones in which various technological solutions are examined. These may include water quality improvement technology, or stimulating multifunctionality and capturing nature values via creative integration of infrastructure, housing, recreation and nature. In terms of evaluation, other spatial equity criteria and aggregation functions can be considered.

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Appendix Table A1. Environmental quality (index, [0,100]) and economic welfare (million Euro) per polder for the four scenarios.

Polder	Reference		Agriculture		Nature		Recreation	
No.	Environmental quality	NPV	Environmental quality	NPV	Environmental quality	NPV	Environmental quality	NPV
1	42.7	23.9	44.3	32.4	42.7	23.9	42.7	16.3
2	43.4	22.1	42.6	28.2	43.4	22.1	43.3	22.1
3	39.6	3.6	39.6	8.5	39.6	3.6	39.6	-4.9
4	45.2	45.2	45.2	43.9	45.2	45.2	45.2	35.9
5	37.6	4.5	37.8	10.6	47.6	-30.4	46.8	37.8
6	53.3	72.0	52.9	70.2	53.6	71.3	53.6	64.9
7	41.8	2.7	41.6	6.4	50.3	-39.2	49.7	52.6
8	38.2	5.9	38.2	13.8	47.1	-39.5	46.7	58.2
9	41.8	2.3	41.8	5.3	49.1	-32.7	43.1	43.2
10	42.5	2.3	42.6	5.3	48.6	-32.7	48.9	35.3
11	48.5	3.2	48.5	0.0	48.5	3.2	48.5	3.2
12	41.6	97.9	41.6	96.5	41.4	97.9	41.5	194.4
13	45.4	52.8	45.2	53.4	48.1	49.3	46.1	57.0
14	46.7	2.7	46.0	3.2	53.8	-39.2	53.1	41.2
15	45.4	19.8	45.6	22.9	45.5	19.8	45.5	19.8
16	48.8	0.0	48.8	0.0	48.8	0.0	48.8	-18.5
17	44.9	70.2	48.6	70.2	49.4	70.2	46.5	59.4
18	40.1	3.6	40.4	4.3	47.1	-52.3	47.1	69.4
19	48.6	0.9	48.7	2.1	48.4	0.9	48.4	-4.1
20	36.1	7.7	36.1	18.1	43.7	-111.2	40.4	144.8
21	42.7	50.2	42.3	43.4	49.6	-3.4	48.5	109.7
22	41.0	0.5	41.0	0.0	44.4	0.5	42.7	-0.3
23	36.3	81.8	37.1	82.3	47.4	56.1	45.5	105.1
24	40.4	11.0	39.8	14.0	50.0	-6.5	49.8	26.0

Appendix Table A1 Cont'd. Environmental quality (index, [0,100]) and economic welfare (million Euro) per polder for the four scenarios (continued).

Polder	Reference		Agriculture		Nature		Recreation	
No.	Environmental quality	NPV	Environmental quality	NPV	Environmental quality	NPV	Environmental quality	NPV
25	41.1	1.4	40.8	3.2	51.9	-10.3	51.4	11.5
26	47.3	2.7	47.3	6.4	47.1	1.6	47.1	-3.0
27	36.1	21.0	39.2	25.9	45.7	-8.1	44.0	52.1
28	41.6	38.5	41.5	39.1	51.1	10.5	50.1	70.3
29	47.2	140.3	47.2	140.3	52.5	140.3	51.8	271.9
30	45.4	63.0	45.4	61.1	52.1	35.0	52.5	96.2
31	46.6	71.5	46.5	73.3	53.0	61.0	52.3	76.2
32	43.4	53.6	45.4	53.7	51.5	46.6	49.0	61.9
33	48.8	26.3	48.8	26.3	48.8	26.3	48.8	26.3
34	49.4	96.5	49.4	96.5	49.4	96.5	49.4	96.1
35	45.9	429.9	45.8	429.9	45.9	429.9	45.7	846.5
36	38.8	2.7	38.8	6.4	38.8	2.7	38.8	-8.7
37	38.5	2.3	38.5	5.3	38.5	2.3	38.5	-7.5
38	50.3	22.4	50.3	29.1	50.3	22.4	50.3	14.0
39	40.1	4.1	39.4	4.8	49.5	-59.5	49.9	78.5
40	35.3	21.1	34.9	21.7	46.0	-35.5	45.3	87.2
41	42.4	67.3	42.6	68.3	50.2	21.9	48.9	121.4
42	45.1	31.0	44.0	37.7	52.2	-8.1	50.8	68.9
43	47.4	6.4	47.5	14.9	47.9	5.7	47.9	-3.6
44	51.4	12.4	51.9	17.3	51.7	11.7	51.7	12.4
45	47.9	1.8	46.8	4.3	48.1	1.1	48.1	0.7
46	46.0	13.7	46.1	20.4	53.7	-24.8	52.3	59.4
47	44.8	3.2	45.0	7.4	53.7	-45.8	52.3	61.4
48	49.7	0.0	50.2	0.0	50.2	0.0	50.2	-17.6

Appendix Table A1 Cont'd.. Environmental quality (index, [0,100]) and economic welfare (million Euro) per polder for the four scenarios (continued).

Polder	Reference		Agriculture		Nature		Recreation	
No.	Environmental quality	NPV	Environmental quality	NPV	Environmental quality	NPV	Environmental quality	NPV
49	41.5	18.0	41.5	18.6	51.6	14.5	50.1	19.3
50	48.8	26.3	48.7	26.3	49.0	25.6	49.0	26.3
51	50.2	9.6	50.2	8.7	50.2	9.6	50.2	9.6
52	37.1	31.8	37.1	32.7	46.2	-52.1	45.8	129.0
53	30.2	1.8	33.6	4.3	41.9	-12.9	38.8	5.1
54	44.7	1.4	44.5	3.2	44.7	1.4	44.7	0.6
55	51.6	0.5	51.6	1.1	51.6	0.5	51.6	0.0
56	47.8	122.8	47.7	122.8	53.0	122.8	52.9	243.5
57	42.6	39.2	42.7	44.7	49.7	-24.4	49.2	113.6
58	40.7	18.0	41.7	18.6	47.8	13.8	46.5	21.7
59	48.9	174.4	48.9	165.3	48.9	174.4	48.9	174.0
60	40.6	10.1	42.4	12.0	48.8	-1.0	47.2	22.1
61	51.1	0.0	51.1	0.0	51.1	0.0	51.1	0.0
62	38.1	35.1	39.3	35.1	47.7	34.4	46.5	35.1
63	37.0	11.5	37.3	15.2	37.2	10.8	37.2	11.1
64	38.2	19.4	36.5	21.8	36.8	18.7	36.8	16.0
65	43.4	26.3	43.6	26.3	43.2	25.6	43.1	22.0
66	51.9	1.4	51.7	3.2	51.9	1.4	51.9	1.4
67	41.5	2.7	42.3	6.4	41.4	2.7	41.2	2.7
68	35.3	1.8	35.5	4.3	45.6	-12.9	44.9	9.9
69	41.0	20.1	39.8	23.7	47.2	-1.6	45.4	33.3
71	45.7	8.8	46.3	8.8	46.4	8.8	46.4	8.8
72	35.7	11.5	35.8	12.0	44.8	-30.5	44.5	61.4
73	36.4	2.7	36.5	0.0	36.1	2.7	36.1	2.7